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POSSIBILITIES FOR COUNTERACTING THE PRODUCTION OF DEFECTS IN SEMICONDUCTOR DEVICES ENCASED IN SYNTHETIC MATERIALS

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Electronic devices containing semiconductor elements, such as diodes, transistors and integrated circuits, are relatively easily subject to various types of defects during several stages of production (manufacture of elements, sealing, final treatment). The causes of such defects are quite various, and have already been discussed in another article (1). Now, factors have been introduced in successive phases of the technological process, by whose observation many defects can be avoided. Some damage is unavoidable and is expected by the producers; some of it, however, can be avoided by observing the proper conditions: for example, better control of production processes, the introduction of masking resins, which protect the semiconductor element, etc., thanks to which the production output, as well as the longevity and reliability of semiconductor devices, are increased.

The Manufacture of Electronic Devices

During the manufacture of semiconductor devices, many defects arise through the presence of various types of impurities, which lower the output and the quality of production. In order to counteract this, it is necessary to apply efficient control to every stage of production. It is then possible to detect and to avoid contamination from air, water, chemicals etc. (2). Elimination of impurities is, in fact, a relatively simple problem, since they can be eliminated through the use of air filters, deionizers for water, drying chambers with laminar air flow, "clean rooms" etc. Organic

contamination from sheets of semiconductors can be eliminated by the application of the proper solvents, and also by the much more efficient method of ion bombardment. Ionic contamination, the most harmful, can easily be eliminated at this stage by repeated rinsing with purified water or weak acid.

While handling the sheets, it is necessary to pay particular attention to the semiconductor chips themselves, because their mechanical strength is very small. The final treatment of the sheets must be exceptionally careful--one must avoid increased stress, shocks, cracks, excessive amounts of emery powder in polishing, impacts, etc.

At every operation throughout the entire technological process one must remember that working conditions during the manufacture of semiconductor elements must be maintained in a state of exceptional cleanliness. During the manufacture of a given structure, the basic requirement is strict adherence to the technological regime.

The reliability of electronic devices is a result equally of a correctly made element, specifically the active casing, as of the suitably well-matched materials from which the device is made. The casing must protect the device against all environmental influences, above all against moisture, which is the direct cause of many defects (the appearance of leakage current, corrosion of openwork, internal electrochemical effects). In order, however, to minimize as far as possible the effects of moisture on the device, the metal parts (wire leads, openwork) must be made from the proper metals or their alloys, resistant to environmental influences, but at the same time amenable to final treatment. Detailed requirements regarding the metal to be used for internal connections have been given by E. D. Metz (3). Theoretically, such a metal should combine the best characteristics of several metals (the ease of mounting and soldering

of gold, the conductivity of silver, the resistance to corrosion of rhodium, the ease of etching of aluminum, the adhesiveness to a base of molybdenum, the mechanical strength of steel, etc.). We know that all these requirements cannot be met simultaneously, but one must attempt to fulfill them to the highest possible degree.

The external portion of the openwork can be protected against corrosion by coating it with a layer of tin, which has proven better than, for example, a layer of gold (due to its susceptibility to so-called pitting corrosion). Of course, this coating must be uniform, because any inconsistency in the coating brings about results opposite from those intended (4). In order to prevent such defects as, for example, purple sickness, one must avoid, as much as possible, heating of the devices to excessive temperatures; this is particularly important where aluminum-gold junctions are concerned (thermocompression).

One method of protecting the metal spray coating on a semiconductor element against corrosion is to cover it with an appropriate protective layer. This is not complete protection, especially in the case of defects like discontinuities, but with defects like short circuits, the speed of dissolution and renewed precipitation of the metal (gold) is significantly reduced because of the presence of a passivating layer.

A definite innovation, and at the same time a perfecting of the production of silicon PNP transistors intended for sealing with synthetic materials, was the introduction of a system for sealing semiconductor crystals--a protective layer of silicon nitride. Such a system is also used in the production of integrated circuits by Bell Laboratories. In addition, it has been shown that one can improve the yield of NPN transistors by about 1.5 to 1.8 times, by heating previously prepared silicon chips at a temperature of about 500°C for

two hours in a gas mixture containing 95% nitrogen and 5% hydrogen. After sealing with a synthetic material, the reliability of these transistors equals that of "hermetically sealed" devices (5).

The Sealing of Electronic Devices with Synthetic Materials

The prevention of defects in manufactured and inspected, and therefore efficient semiconductor devices, through the use of synthetic materials, is widely practiced throughout the world today. Besides complete casings of synthetic materials, the semiconductor crystal is frequently covered first with masking resins; this applies not only to encapsulated devices, but also to "hermetically sealed" devices.

The selection of materials for the initial coating and for the sealing of the electronic devices must undergo careful analysis of the conditions in which the device will operate, as well as which defects it is subject to. The parameters of the material must meet many requirements, so that the casing produced from it performs correctly and reliably during the same time as does the semiconductor device itself.

The main purpose of sealing is the prevention of permeation and condensation of moisture upon the hydrophilic surfaces of the semiconductor elements encased by the material, and upon the metal parts. The protective mechanism against moisture consists in the deactivation of likely sites for the absorption or condensation of moisture (6, 7). The material chosen as a sealant must either react chemically with the sealed surface, or must be strongly adsorbed onto it. Besides this, it must protect it mechanically. In the selection of a specific material, therefore, the following parameters must be considered:

1) elimination of paths for moisture;

2) thermal stability (degradation of the properties of the sealant layer must not follow at increased temperatures);

3) resistance to the action of moisture;

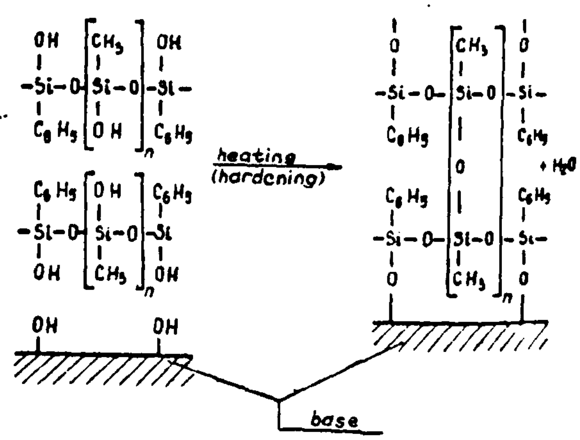
4) electrical and mechanical properties: high surface resistance and thorough and high dielectric resistivity, a corresponding coefficient of loss and dielectric constant in conditions of high moisture, corresponding mechanical strength;

5) lack of reaction upon the parameters of the device-- lack of contamination of the sealant layers;

6) resistance of the casing to final treatment;

7) ease of use.

There are two major types of material suited to the sealing of electronic devices: silicon resins and epoxy resins. Silicon resins serve not only for the manufacture of casings, but also for use as masking materials. The mechanism by which some silicon resins and built-up bases behave is shown in the diagram.



As a result of the reaction of the hydroxyl groups of the resin with the hydroxyl groups located on the sealed surface, oxygen bridges form. In this way the interphase surface and places of adsorption of water are eliminated.

At the sites at which the material comes into contact with metal, a better connection can be achieved through proper preparation of the surface of the metal, or application of very thin connecting bases or layers. There are two types of silicon resins used as preliminary coatings. One type is a material which hardens to rigidity, and is used when rigid protection of the physical element of the semiconductor is necessary. The second type is a more elastic coating, which is used when the electronic device is subject to great fluctuations of temperature. Such a coating prevents damage to the device resulting from differences in the expansion coefficients of the materials in contact. Masking resins afford additional protection to the connections and to the semiconductor element in case of impurities and mechanical damage, reduce leakage current and prevent the reversal of semiconductor characteristics, depending on the particular type of resin used.

When syntnetic materials are used, prevention of the reversal of semiconductor characteristics is quite essential. Silicon compounds, depending on their relative proportions of aromatic and aliphatic groups, are distinguished by specific properties. A resin with a higher proportion of aliphatic groups displays more P-type characteristics, does not tend toward the reversal of a P-type surface, and therefore must be used for sealing NPN regions. The reverse is the case of resins with a higher proportion of aliphatic groups. They have the character of an electron donor; they form more of an N-type surface, and lend themselves to sealing PNP devices.

Epoxy resins used for sealing semiconductor devices must be, above all, free from ionic contamination. When they are used as sealants, selection of they qualitatively appropriate fillers, softeners and hardeners, as well as stabilization of time, temperature and conditions of hardening are also necessary (3). It must be remembered that the properties of epoxy resins can be modified over a broad range. High-temperature properties, frequently required in semiconductor device casings, are exhibited by the new epoxy waxes, as well as by resins hardened by acid anhydrites and by aromatic amines. R. C. Olberg (9) has discussed the results of research into the effects of the purity of resins, fillers, hardeners, accelerators etc. on the final properties of epoxy resins. Thus, adherence to a specific methodology and a consistent quality of raw materials is not without importance. Even a small change in their relative makeup can have a great influence on the final characteristics of semiconductor devices.

The most economical and most widely used method of sealing semiconductor elements with synthetic materials is low-pressure injection compression (10, 11). During the compression of the elements it is necessary to observe very strictly the parameters given in the production process, because their nonobservance, or insufficiently careful procedure, can lead, for example, to damage to the delicate connections, or to a degradation of the electrical, mechanical or climatic properties.

It is essential as well to give weight to the proper selection of the coefficients of expansion between the casing and the wiring of the device. These coefficients must agree, or be so well matched that the wire is pressed through the surrounding material. The possibility of permeation of moisture into the assembly is thereby reduced.

Final Treatment and Storage

After the complete sealing of the electronic devices with synthetic materials, there follows the so-called final treatment, during which it is necessary to be careful that the devices now ready are not damaged. Final hardening must be carried out in carefully cleaned ovens, for in the case of casings made from epoxy materials, volatile impurities occurring in the oven (epichlorohydrines) can contribute to the degradation of the parameters of uncontaminated devices (9).

If the terminal leads are to undergo tinning, this operation must be performed as rapidly as possible, because an excessively long supply of heat can lead to microscopic cracks in the casing at the point of contact with the openwork.

Bending of the wires must also be carefully performed, preferably through the use of special equipment, because otherwise, as a result of the action of flexor tension, the casing can be subject to tiny cracks near the connections, and thereby permit the easy infiltration of moisture.

Encapsulated electronic devices have limited mechanical strength. Therefore, one must avoid excessive stresses or loads, taking into account the appropriate packing units (cases). Storage conditions must also be suitable; that is, such that the sealed semiconductor devices are preserved at room temperature and in conditions of low humidity.

The reliability of performance of electronic devices in casings of synthetic materials is equal to that of "hermetically sealed" devices. Thanks to the ever-better properties of these materials, the performance of semiconductor devices in such casings frequently

equals that of devices in the traditional ceramic-, metal- and glass-type casings, at considerably lower production costs. Observance of the conditions discussed above, which prevent defects that could arise during the fabrication of the devices themselves and during their sealing, causes an additional reduction in failures; further, the devices certified as good, besides effecting an increase in use and a decrease in cost, can be used successfully under various conditions of temperature and humidity, without perceptible change in their electrical characteristics.

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